NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM

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A NEW APPARATUS FOR MEASURING THE TEMPERATURE AT MACHINE PARTS ROTATING AT HIGH SPEEDS

By E. Gnam

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A NEW APPARATUS FOR MEASURING THE TEMPERATURE AT MACHINE PARTS ROTATING AT HIGH SPEEDS*

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SUMMARY

After a brief survey of the available methods for measuring the temperatures of machine parts at high speed, in particular turbine blades and rotors, an apparatus is described which is constructed on the principle of induction. Transmission of the measuring current by sliding contacts therefore is avoided. Up-to-date experiments show that it is possible to give the apparatus a high degree of sensitivity and accuracy. In comparison with sliding contact types, the present apparatus shows the important advantage that it operates for any length of time without wear, and that the contact difficulties, particularly occurring at high sliding speeds,are avoided.

When using electrical methods for measuring the temperature at rotating machine parts like turbine blades, rotor disks, and so forth, it is very difficult on account of the frequently very high running speed accurately to transmit to the indicator the usually weak currents or voltages.

For measuring the thermoelectric potential at a rotating machine part, the following methods can be applied:

1. The measuring current can be transmitted to the indicator by sliding or dipping contacts.

2. The measuring current can be transmitted to the indicator by induction. (This method was proposed by H. Kühl.)

*"Über ein neues veräg zur Temperaturmessung an Schellanfenden Maschinenteilen." Motortechnische Zeitschrift, vol. 5, no. 10, Oct. 1943, pp. 289-291.

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The first method has often been applied (see reference 1), but the second has not yet been used as far as the writer knows.

It is possible in both cases (in the second even desirable) for reasons of simplicity and accuracy to replace the deflection method by a method of compensation, based on suitable compensation of the measuring voltage by an auxiliary voltage, and determine the value of the second for zero deflection of the indicator.

It is necessary to mention a third method which has shown satisfactory results when measuring the temperature of parts in translatory motion. Here the thermoelectric potential is recorded only during a short period by sliding contacts in each limit position of the structural part. This can be done, however, only with the help of a compensation voltage. (See reference 2.)

Compensating the thermoelectric current is readily effected on the principle illustrated in figure 1 by raising the temperature of the cold junction, rotating inside the shaft of the measuring apparatus, to that of the hot junction by a small, fixed, controllable thermostat. For measuring purposes it then suffices to read the thermostat temperature by a mercury thermometer or thermocouple.

If the compensation method is compared with the deflection method when using sliding contacts, the first will be preferable since variations in contact resistance between brushes and slip ring, because of oxidation, for example, are not included in the measurement, and consequently need not be allowed for. Errors in the deflection method also can be caused when (especially at high sliding speeds) the current-collecting brushes are momentarily lifted on account of slight roughness of the ring surface. This may cause considerable acceleration forces and when the thermoelectric potential is directly recorded, the millivoltmeter will only indicate the mean value over the period of contact between brushes and slip ring. This error is avoided when compensation used. Furthermore, special calibration of the thermocouple placed in the turbine blade or rotor will be necessary. This is very troublesome in most cases.

A disadvantage of the compensation method is the necessity of bringing the cold junction to measuring temperature at each measurement. Some waste of time is then unavoidable, although suitable construction of the thermostat (low heat

capacity and insulation against radiation loss) reduces this to a few minutes.

In recent experiments at the DVL with commutators, perfect current transmission was obtained by using a copper slip ring and copper wire or mesh brush in association with an auxiliary graphite brush which fulfills the dual purpose of cleaning and lubricating.

Some time ago experiments were made with the sliding contact apparatus shown in figure 2. Results up to date prove that a reliable transmission of the thermoelectric potential is possible in the absence of high peripheral speeds. Investigations are proceeding whether measuring errors can be obviated at higher speeds, particularly when the compensation method is applied. Further test reports will appear at some future date.

When a method is used in which the measuring voltage is transmitted by induction, the errors which may occur during direct transmission of the measuring voltage from the rotating to the fixed part can be avoided. The main advantage of such a type of temperature-measuring apparatus is that it can be used within the range of particularly high speeds of rotation when, for reason of design, the sliding speeds become too high for contact measurement. The constructional principle of such an apparatus, used in the present case for measuring blade temperatures of an exhaust gas turbine, is shown in figure 3. To safeguard the apparatus against undesired rise in temperature, it was coupled to the turbine by a relatively long shaft (about 300 mm).

The thermoelectric current flowing between the hot and cold junctions is fed through a coil which rotates with the two junctions (primary coil). Its construction is similar to that of the shuttle armature of a small generator. The field generated in this coil induces an alternating voltage in two fixed secondary coils which surround the primary coil and have a great number of turns. The voltage is proportionate to the number of ampere turns on the primary coil and its revolutions per minute. The voltage in the secondary coils is amplified by a simple capacity-resistance amplifier and recorded (indicated) by a cathode ray oscillograph or any other suitable alternating-current indicator. For measuring temperatures of engines with constant revolutions per minute (the temperatures of commutators in synchronous motors, for example) the deflection method can be applied, provided a calibration curve is plotted for the corresponding revolutions

per minute. For measuring temperatures at parts with variable revolutions per minute (blades of gas turbines or highly loaded gear wheels, etc.), it is advisable to compensate the thermoelectric current in the thermostat by heating the rotating cold junction, in order to counteract the influence of rotation.

When the induction apparatus was tested, a few difficulties arose. These, however, were overcome. Parasite voltages were induced, due partly to the magnetic field and partly to the ball bearings supporting the shaft, and usually having a certain amount of remanent magnetism that could not be compensated. These voltages caused unreliable readings. In the case of the rotating part the parasite potentials came from the primary coil carriage and winding.

The prevention of eddy current effects in the primary coil carrier is of importance. It, therefore, was decided to use primary coils made of plastic material after it had been ascertained that its strength was sufficient to take the strain of the high peripheral speeds required for measuring.

The parasite voltages in the primary coil windings mainly induced by the earth field are eliminated by placing the two symmetrically arranged halves of the winding (shuttle armature) not in series but in push-pull. The result is that the current induced in the primary circuit by the earth field neutralizes itself in the two oppositely wound rotor coils. The thermoelectric current flowing through the carrier coil at the same time generates a field which is such that two north or south poles always occur at the two outer ends of the primary coil. The two fixed secondary coils then must be correspondingly arranged. With complete symmetry of the two halves of the winding, the earth field influence is thus entirely eliminated. In view of the fact that some asymmetry of the two halves of the winding is unavoidable, and particularly because protection is needed against the ball-bearing magnetic field, which principally induces currents in the fixed secondary coils, the entire coil system and bearings were completely magnetically screened. (See fig. 4.) The casing used for this purpose was made of high μ alloy, which is particularly suited for magnetic screening owing to its high initial permeability and low coercive force.

The instrument, which is particularly designed for measuring temperatures at exhaust gas turbine blades and wheel

disks rotating at 5000 to 24,000 rpm, has sensitivity characteristics as shown in figure 5 plotted for two different degrees of amplification of the secondary voltage dependence on the speed of rotation of the instrument. The characteristics were determined on a small test bench, the instrument being driven by electromotor gears up to 18,000 rpm. The usual thermocouple was replaced by one with constant ohmic resistance, and placed inside the shaft connecting the turbine to the instrument. By heating the cold junction rotating inside the thermostat, a temperature differential is produced with reference to the junction in the connecting shaft which is at room temperature. When several thermocouples are used at the same time, the junction measuring the temperature must be connected to the one rotating in the thermostat. This is done by a circular double pole plug inside the hollow shaft with sliding contacts which are pressed against the segments of the contact rings by centrifugal force. A pin working in a slot in the hollow shaft, and rigidly connected to a sleeve rotating with the latter, displaces the sleeve and consequently also the sliding contact rigidly connected to the former by the pin. The appropriate hot junction is, therefore, always connected to the cold junction. (See fig. 6.) The sliding sleeve is moved by a fork. The instrument is adjusted to three measuring positions.

The instrument functioned satisfactorily when temperatures were measured at an exhaust turboblower with internally cooled blades. A thermocouple was fixed half way along the leading edge of a turbine blade, as well as at the blade root and on the motor disk. With a gas entry temperature of about 825° C, the blade temperatures were plotted against revolutions per minute as shown in figure 7. During measurement, the thermostat temperature was adjusted to that of the hot junction by heating, or cooling down from a higher temperature. When the requisite temperature was reached, the induced alternating-current voltage became zero. The difference - that is, the accuracy with which the compensation point could be determined - amounted to approximately 1.5 to 2 percent of the indicated thermal potential.

The drop in blade temperature with increased turbine speed is, firstly, due to the decrease of the stagnation temperature (reference 4) also plotted in figure 7 and the improved cooling action due to the increased flow of cooling air, conditioned by the churning action which increases with revolutions per minute (reference 5).

Translation by J. Helledoren.

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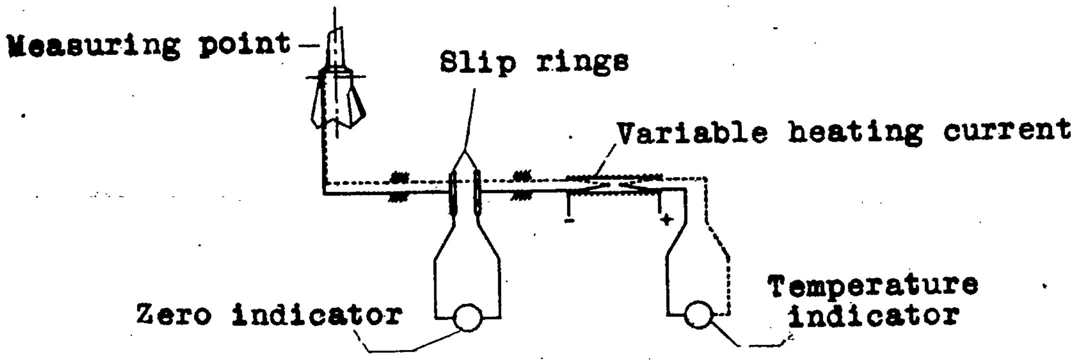

Figure 1.- Measuring the temperatures of rotating machine parts according to the compensation method.

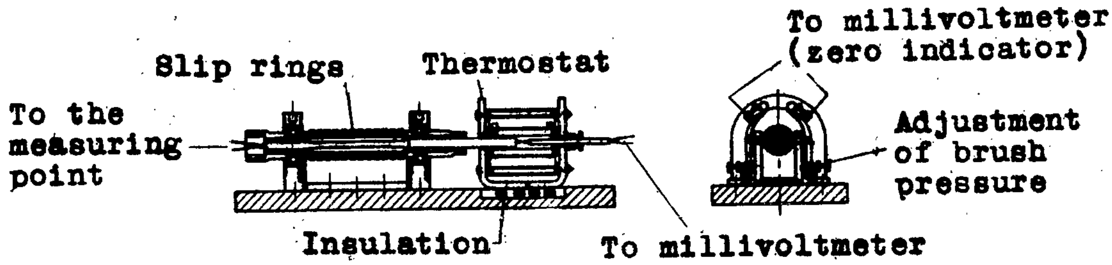

Figure 2.- Slip ring apparatus for measuring the temperatures of rotating machine parts according to the compensation method.

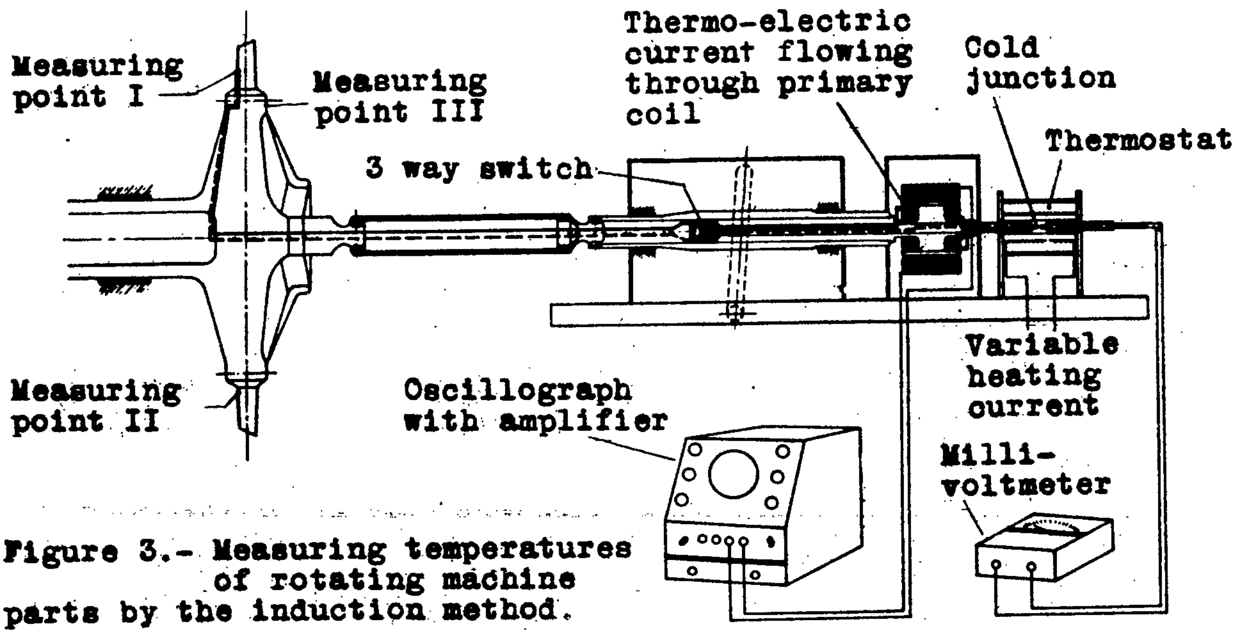

Figure 3.- Measuring temperatures of rotating machine parts by the induction method.

(See reference 3)

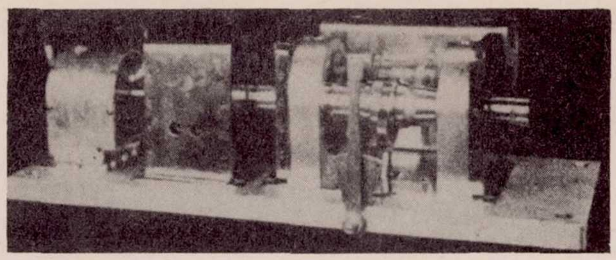

Figure 4.- Apparatus for measuring temperatures at 5,000 to 24,000 rpm by the induction method.

Primary coil resistance, 8Ω
Loading resistance, 7.9Ω

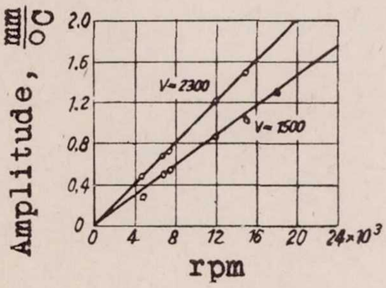

Figure 5.- Sensitivity/rotation speed curve of temperature measuring apparatus with five fold amplification.

(A) Gas temperature in front of nozzle, t_g = 825 °C.
(B) Stagnation temperature 85% velocity/heat transformation.
(C) Temperature at the middle of blade leading edge.
(D) Temperature at leading edge of blade root.

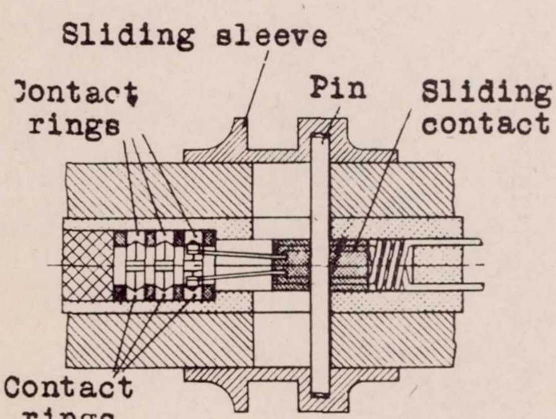

Figure 6.- Measuring point commutator built into the shaft of the temperature measuring apparatus.

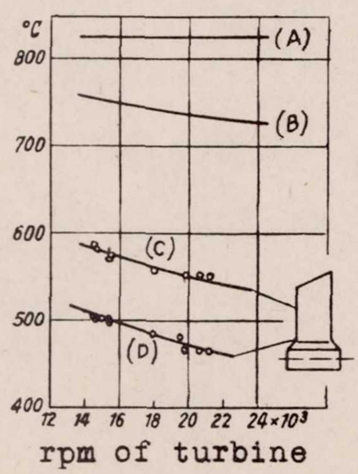

Figure 7.- Blade temperatures of an exhaust gas turbine, measured by the induction method.

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Aircraft
Turbines - Blades - Temperature

x Rotors - Temperature
x Disks, Rotating - Temperature